# Network Edge & Core
# Delay, Loss, and Throughput
# Protocol Layers

**CE 260 Computer Networks**

THE UNIVERSITY OF
SOUTHERN MISSISSIPPI

# Network Edge

- End systems:
  - Clients: tend to be desktops, laptops, smartphones, etc.
  - Servers: more powerful machines that store and distribute web pages, stream video, email, etc.
  - Servers reside in **data centers**

- Access network: network that physically connects an end system to the path to another end system

- Some access networks:
  - DSL
  - Cable
  - FTTH
  - 5G

- DSL: Digital subscriber line
  - Needs a telephone line to use a digital subscriber line access multiplexer (DSLAM) to connect to the internet. The DSLAM is located at the telephone's company office.
  - The home's DSL converts digital data into high-frequency tones for transmission over telephone lines
    - high-speed downstream channel: 50 kHz to 1MHz
    - medium-speed upstream channel: 4kHz to 50 kHz
    - Two-way telephone channel: 0 – 4 kHz
    - This configuration makes DSL appear as if there were 3 separate links.
      - This way the internet connection and telephone can share the DSL link

- DSL rates:
  - Downstream: 24 and 52 Mbps
  - Upstream: 3.5 and 16 Mbps
  - New standards: up to 1Gbps

  - Because of the difference between upstream and downstream, DSL is **asymmetric**.
  - Rates can vary depending on:
    - Distance and gauge of wire
    - Electrical interference

- Cable internet access:
  - Makes use of the cable television existing infrastructure
  - Cable is referred as an HFC (**hybrid fiber coax**) because:
    - Uses both coaxial and fiber are employed in the system
  - Implements a modem (modulator-demodulator) to connect ethernet devices to coaxial infrastructure
  - Similar as the DSALM, cable uses CMTS (cable modem termination system to convert analog signals from the cable modem to digital format.

- Cable is asymmetrical, giving more transmission rate to the downstream
  - DOCSIS 2.0 and 3.0: typical cable standard
    - Upstream (2.0, 3.0): 30 Mbps, 100 Mbps
    - Downstream (2.0, 3.0): 40 Mbps, 1.2 Gbps

- FTTH: Fiber to the home

  - Provides optical fiber path from the home to the CO (central office)

  - 2 optical-distribution network architectures:
    - AON: active optical network. Switched by ethernet
    - PON: passive optical network. Each home has an **ONT (optical network terminator)**
      - The ONT connects to a splitter, which connects to an **OLT (optical line terminator)**, located in the CO.
      - The OLT provides coverts optical to electrical signals and vice versa.

- 5G
  - Data is sent wirelessly from a provider’s base station to a modem at home or office.
  - Uses beamforming technology, where the antennas are fixed in particular angles for efficient communication

# Network Core

# Packet switching

- End systems exchange **messages**
- Messages are broken down into chunks of data known as **packets**
- Packets travel through **packet switches** (routers and link-layer switches)
- Time to transmit a packet (a packet of L bits at a rate of R bits/sec:
  - $t = \frac{L\ (bits)}{R\ (\frac{bits}{sec})}$

# Store-and-forward Transmission

- In Store-and-forward TX, the packet switch must:
  - Receive the entire packet before it can transmitted
- If the packet needs to travel through different links, then an end-to-end delay can be calculated:

$$t = N\frac{L\ (bits)}{R\ (\frac{bits}{sec})} ; where\ N = number\ of\ links$$

# Queuing delays and Packet loss

- Every packet switch has multiple links. For each link, the packet switch has an **output buffer (or output queue)**
  - Output buffer: stores packets that are about to be sent
  - If an arriving packet needs to be sent onto a link, but the link is busy, the arriving packet must wait in the buffer.
    - Packets suffer **queuing delays** in addition to store-and-forward delays.

- Buffer space in limited
    - If an arriving packet finds the buffer to be full, **packet loss** will occur.
    - The arriving packet or a queued packet will be dropped.

# Circuit switching

- Two approaches on how to move data through a network of links:
  - Circuit switching
  - Packet switching

- Circuit switching:
  - Resources for communications are reserved for the duration of the communication session. For example: a telephone call

- Packet switching:
  - Resources are not reserved. Resources are used on demand, and messages may have to wait.

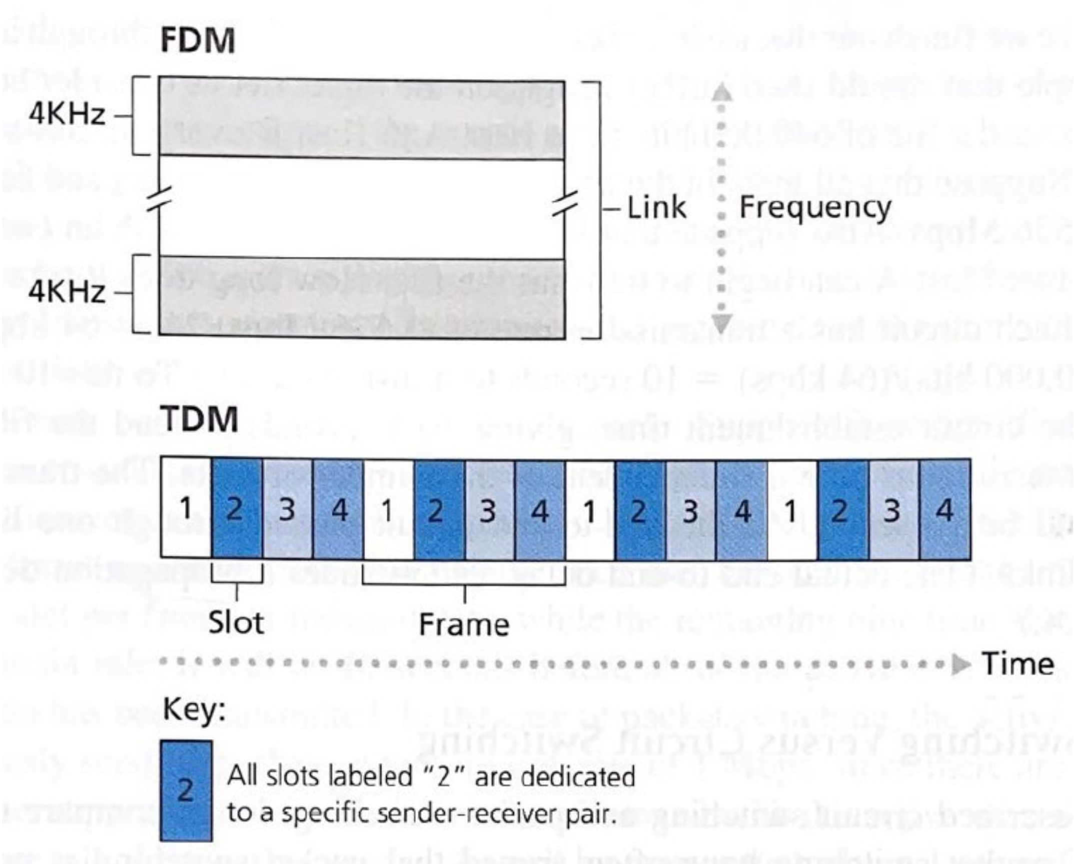
- Circuit switching:
  - Transfer rates are guaranteed to be constant
  - Transmission is reserved to sender-to-receiver once the connection is established
  - An **end-to-end connection** is performed for communication

# Multiplexing in Circuit-Switched networks

- A circuit link implements:
  - FDM (frequency division multiplexing)
  - TDM (time division multiplexing)

- In FDM:
  - The link dedicates a frequency band to each connection for the duration of the connection
    - The width of the band is called: **bandwidth**
    - for example: a telephone network has a 4kHz bandwidth

- In TDM:
  - Time is divided into frames of fixed duration
  - Each frame is divided into a fixed number of slots



# Delay, Loss, and Throughput in Packet-switched Network

- Types of delays in packet-switched networks
  - Nodal processing delay
  - Queuing delay
  - Transmission delay
  - Propagation delay
  - All together make: total nodal delay

- Nodal processing delay:
  - Time required to examine the header's packet and determine where to direct the packet
    - Can include time to check for errors in packet
- Queuing delay:
  - Waiting time for the packet to be transmitted. Will depend on the number of earlier-arriving packets.
- Transmission delay:
  - Assuming that packets are transmitted in FIFO (first-in-first-out), the delay will be a packet of L bits over a rate of R bits/sec (L/R)

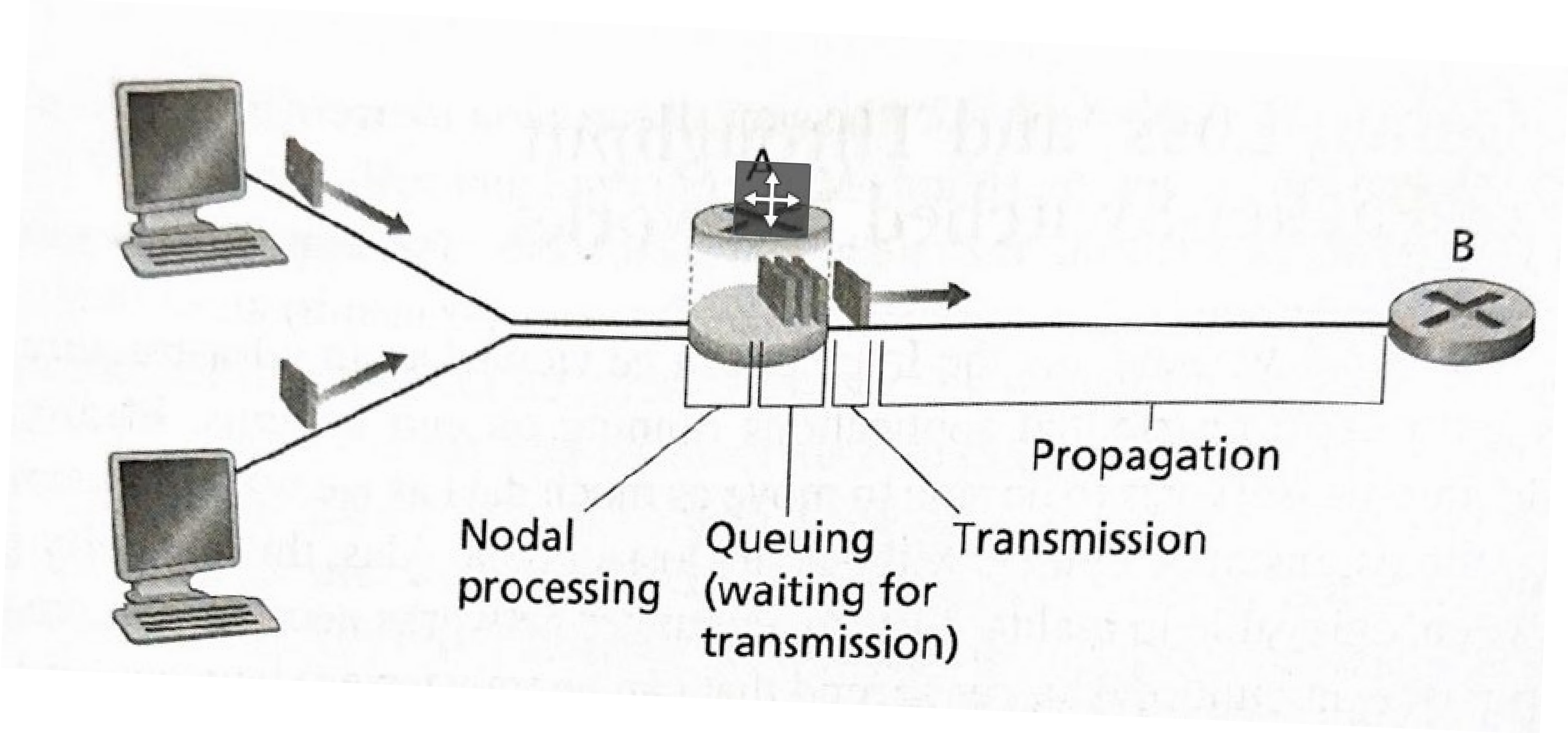
- Propagation delay:
  - Time required for the bit to be propagated through the medium.
    - Will depend if it is
      - Fiber optic
      - Twisted-pair copper
      - Coaxial, etc.
    - Can be calculated by:
      - Distance between router A and B, divided by the propagation speed of the link.

- Total nodal delay can be calculated:

$$d = d_{proc} + d_{queue} + d_{trans} + d_{prop}$$

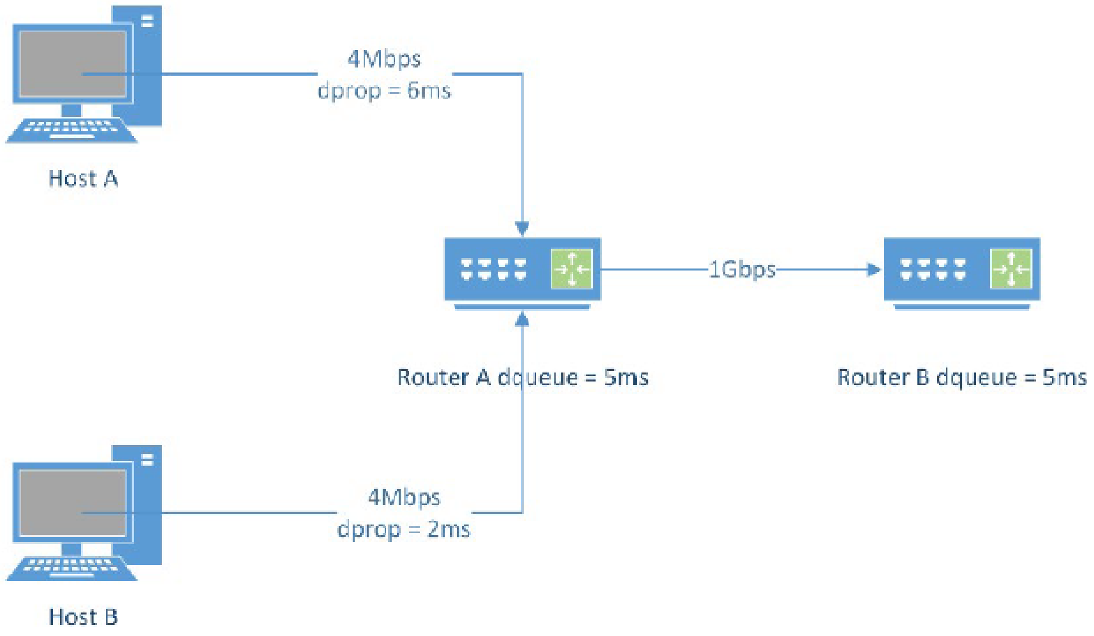
- Total nodal delay end-to-end:

$$d_{end-end} = N(d_{proc} + d_{queue} + d_{trans} + d_{prop}); N = number\ of\ routers\ (links)$$



# Example

Consider the figure below. Assume the two hosts start to transmit packets of 1500 bytes at the same time towards Router B. Suppose the link rates between the hosts and Router A is 4Mbps and 1Gbps between Router A and Router B. One link has 6-ms propagation delay and the other has a 2-ms propagation delay from the hosts to Router A. Both routers have a queuing delay of 5-ms. Propagation delay between Router A and B is 4-ms. What is the total nodal delay end-to-end?



# Example

$$d_{end-end} = N(d_{proc} + d_{queue} + d_{trans} + d_{prop}); N = number\ of\ routers$$

- Packet: 1500 Bytes
- $d_{procRouterA}$ = not specified, so assume 0. Same for Host A.
- $d_{procRouterB}$ = not specified, so assume 0. Same for Host B.
- $d_{queueRouterA}$ = 5ms
- $d_{queueRouterB}$ = 5ms
- $d_{trans}$:
  - $d_{transHostA}$ & $d_{transHostB}$ = Since Host A doesn't need to wait for packets in a FIFO configuration (HostA & HostB initiate transmission) then assume 0.
  - $d_{transRouterA\text{-}RouterB}$ = 1500 Bytes / 1Gbps.

- $d_{propHostA}$ = 6ms
- $d_{propHostB}$ = 2ms
- $d_{propRouterA\text{-}RouterB}$ = 4ms

# Example

$$d_{end-end} = 2(d_{procA} + d_{procB} + d_{queueA} + d_{queueB} + d_{transA-B} + d_{propHostA} + d_{propHostB} + d_{propA-B})$$

$$d_{end-end} = 2\left(0 + 0 + 5ms + 5ms + \frac{1500\ B}{1Gbps} + 6ms + 2ms + 4ms\right)$$

$$d_{end-end} = 2\left(0.01s + \frac{12{,}000\ bits}{1 \cdot 10^9 bps} + 0.012s\right)$$

$$d_{end-end} = 2(0.022s + 0.000012s)$$

$$d_{end-end} = 2(0.022012)$$

$$d_{end-end} = 44.024ms$$

# Throughput in Computer Networks

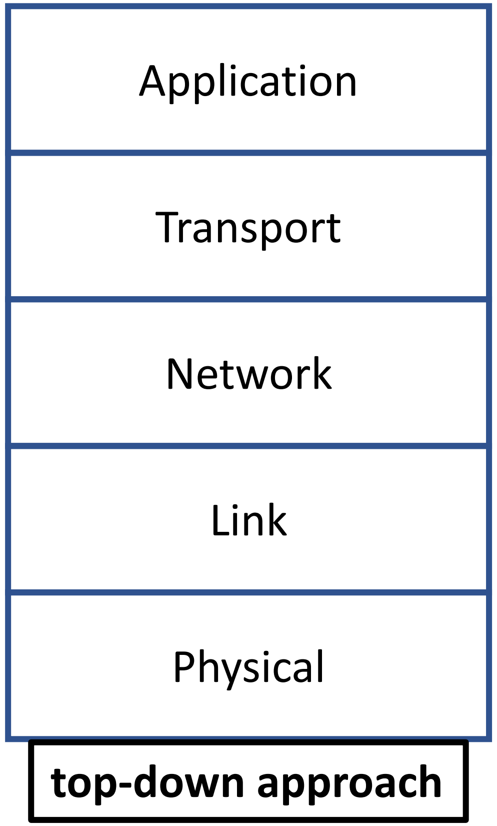
- Instantaneous throughput:
    - Rate (bits/s) at which Host B is receiving a file

- Throughput depend o the transmission rates of the links over which the data flows

# Protocol layers

- The design of network protocols are organized in **layers** to provide structure
  - Each layer perform certain services and uses the services of the layer directly below
  - Some drawbacks:
    - Functionality can be duplicated in certain layers
      - For example: error correction can be duplicated
    - Information may be needed that is present in another layer; violates the goal of layer separation

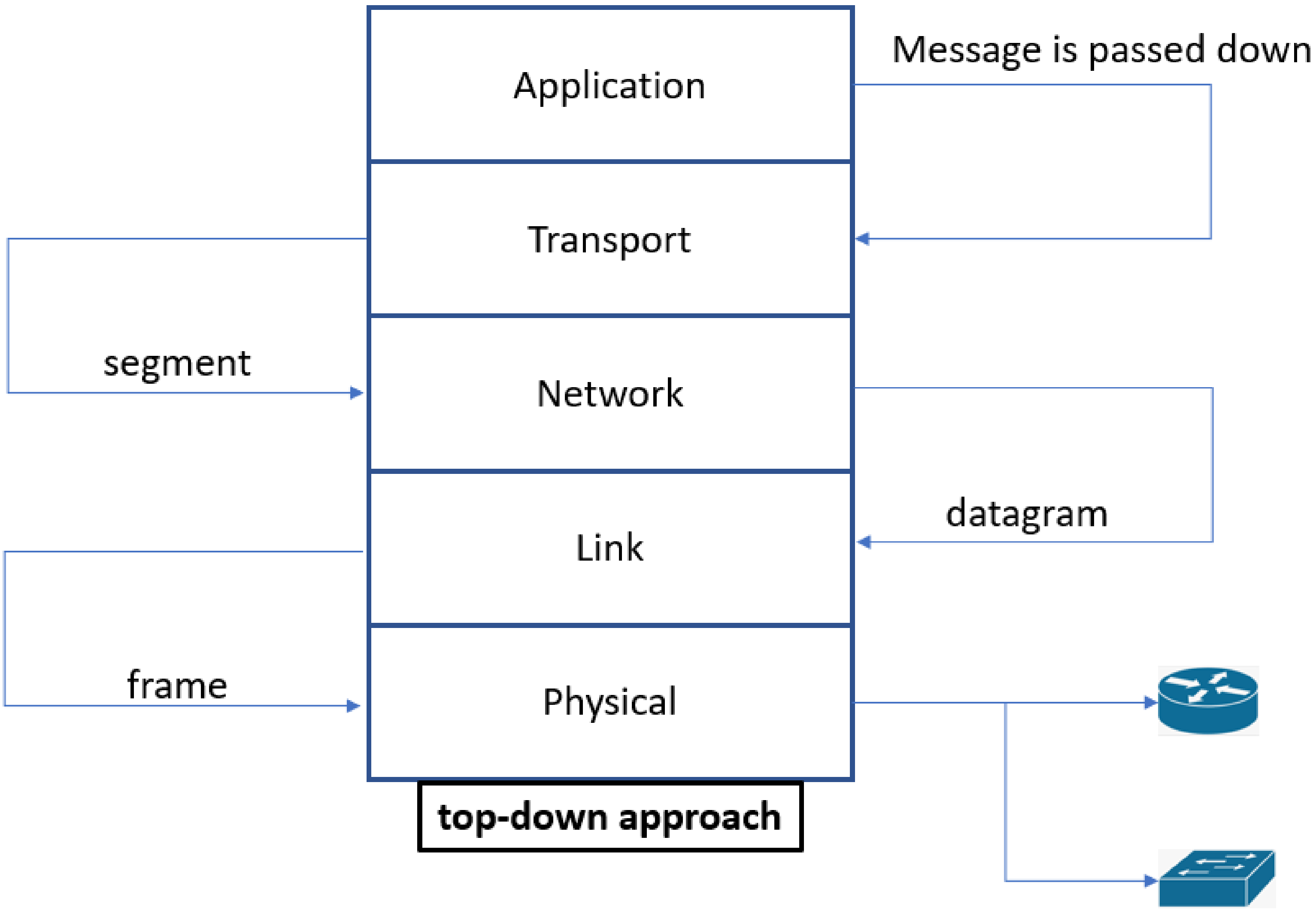
- Application layer:
  - Where network applications and protocol resides. Includes:
    - http: for web requests
    - FTP: file transfer protocol
    - SMTP: simple mail transfer protocol, for email applications
  - In the application layer, packets of information between applications are referred to as: **messages**



- Transport layer:
  - Transport messages between application endpoints. Includes:
    - TCP: transmission control protocol. Connection-oriented, meaning it is built to ensure delivery of messages
    - UDP: user datagram protocol: Connectionless protocol, design for fast delivery, no flow control, no congestion control.
  - In the transport layer, packets are referred to as: **segments**

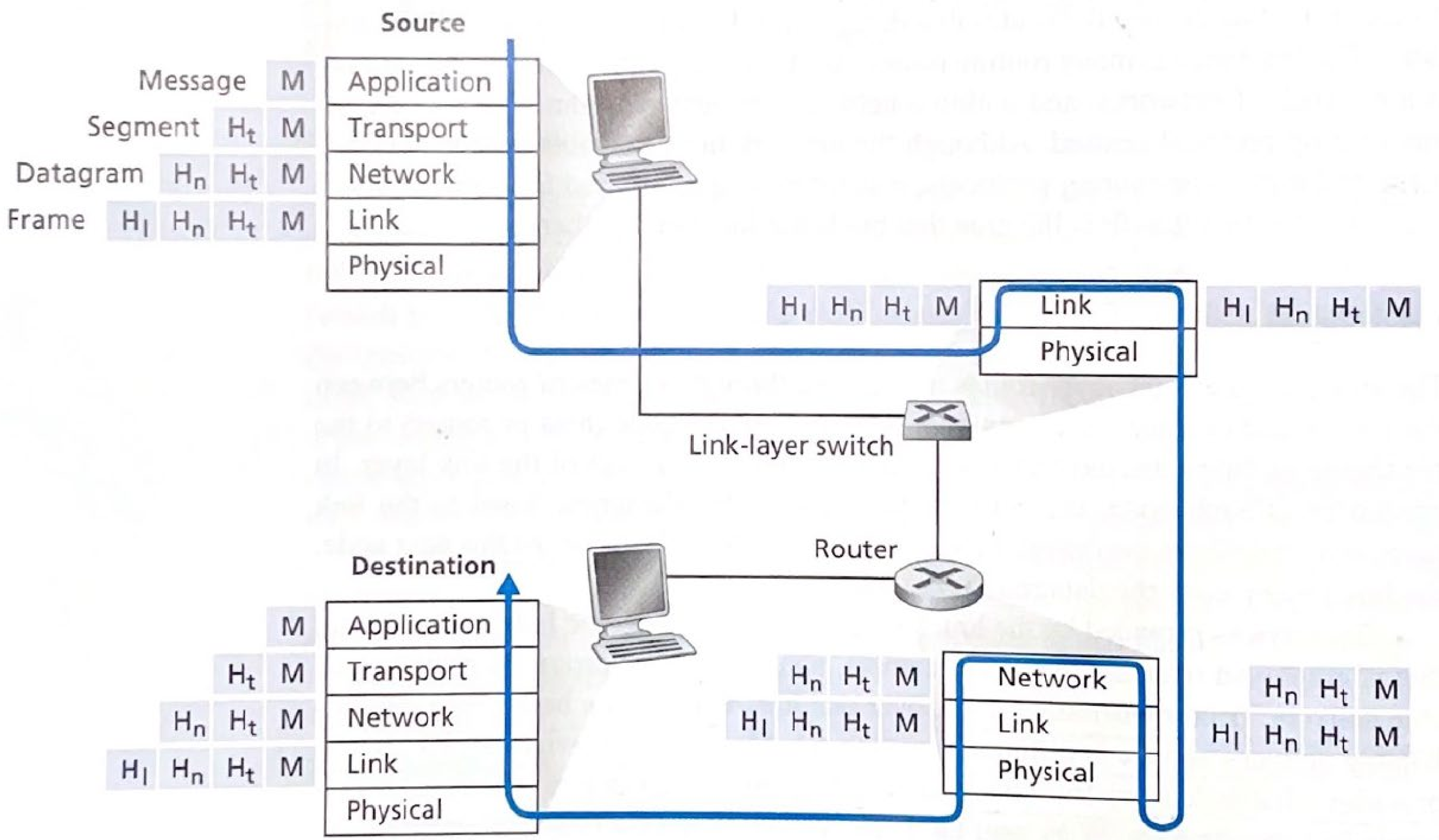
- Network layer:
  - Layer dedicated to move packets (called datagrams) across networks.
    - A host in the transport layer passes a TCP segment and a destination address to the network layer. The network layer delivers the segment to the transport layer in the destination host.
      - Includes: IP (internet protocol) defines the fields of the datagram

- Link layer
  - The network layer passes the datagram down to the link layer, which delivers the datagram to the next node. At this node, the link layer passes the datagram up to the network layer.
  - Some protocols in the link layer include (built for reliability in the link. Not to be confused with TCP, which provides reliability for end systems):
    - Ethernet
    - Wi-Fi
    - DOCSIS protocols
  - Link-layer packets are referred as: **frames**




Router: Layers 1 to 3
Switch: Layers 1 and 2

# Encapsulation



# Encapsulation

- Refer to image in prior slide:
  - M = message
  - $H_t$ = Header from the transport layer
  - $H_n$ = header from the network layer
  - $H_L$ = header from the link layer
- At each layer, every packet has two fields:
  - Header
  - Payload: the payload is typically a packet form the layer above
- Routers implement only layers 1 to 3
- Link-layer switches implement only layers 1 and 2

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